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THE ENIGMATIC CRAB NEBULA AND ITS PULSAR

Martin C. Weisskopf & Numerous Colleagues

Festkolloquium to celebrate the 65th birthday of Peter Predehl
September 16, 2015

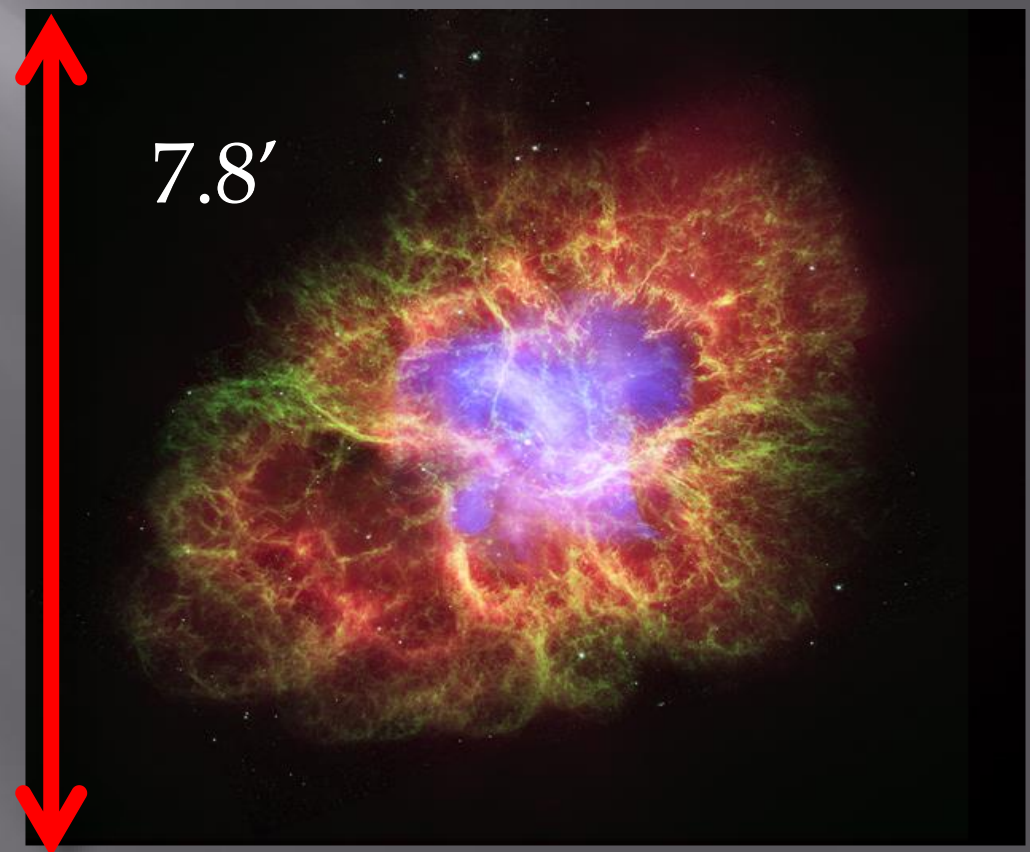
Important references

- Hester, J. 2008, Annual Review of Astronomy & Astrophysics, vol. 46, Issue 1, pp.127-155

- Bühler, R. and Blandford, R. 2014, Reports on Progress in Physics, Volume 77, Issue 6, article id. 066901

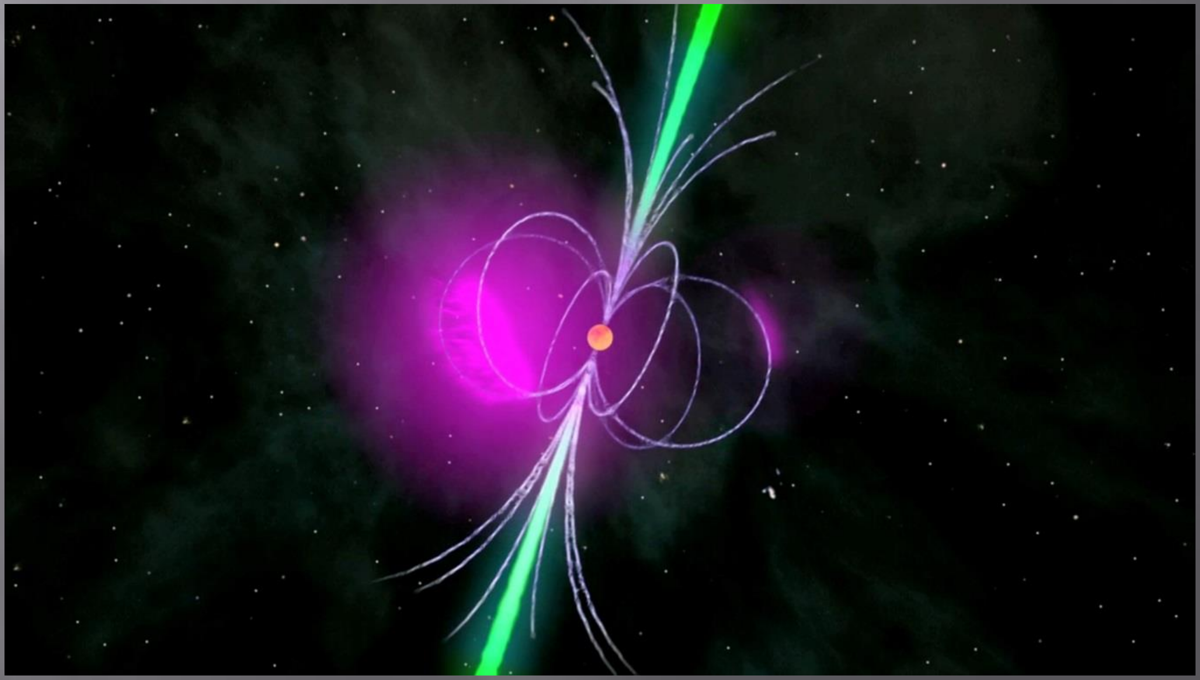
Scales

- X-ray:Blue-Purple-White
- Optical:Green-Yellow
- Infrared:Red
- Distance = 2 kpc
- 1″ at 2kpc is :
  - 0.0093 pc
  - 11.1 light days
  - $3x10^{16}$ cm



How it works

- The fundamental energy source is the spinning (and slowing) pulsar
- Emits a relativistic wind of particles that ultimately shock
- Then the particles radiate via synchrotron emission

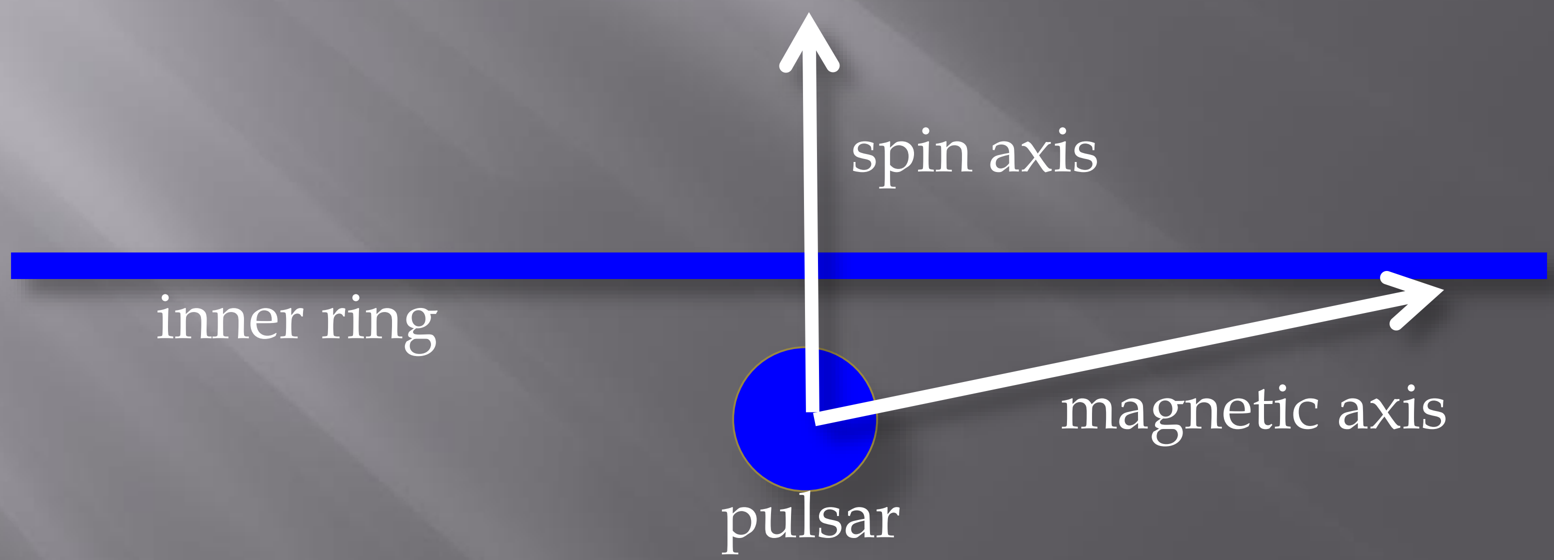


New Findings in the Great Observatory Era

- Discovering the (presumed) shock front by X-ray imaging with Chandra
- Discovering the emission from the X-ray pulsar at pulse minimum
- Performing precision spectroscopic measurements of the X-ray pulse profile as a phase for *all* phases
  - Thank you Peter and the LETG team
- Providing a new look at the geometry of the inner ring and its relationship to the pulsar with Chandra

Best fit geometrical model

- The magnetic field is at 85.5 degrees with respect to the spin axis?

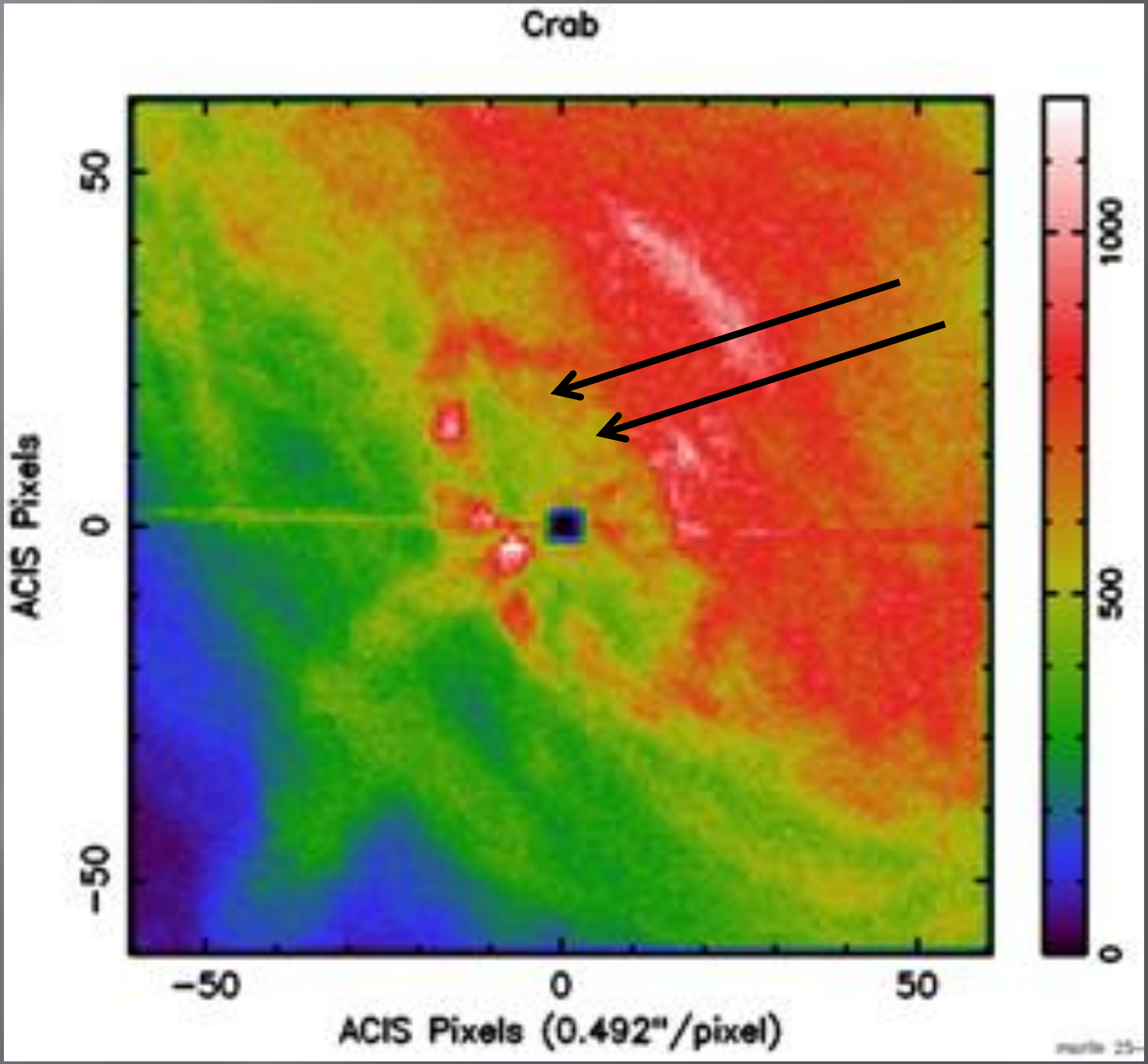


New Findings in the Great Observatory Era - II

- Discovering gamma-ray flares with Agile and FERMI/LAT
- Are we seeing evidence for RT instabilities in the inner ring?
- Searching for the site of the gamma-ray flares with Keck, HST, and Chandra
- Studying the spatial and temporal evolution of the optical and X-ray northern wisps using the Nordic Optical telescope and Chandra
- Performing precision measurement of the radio polarization as a function of pulse phase at 1.4 Ghz
- Characterizing the inner knot of the Crab: The site of the gamma-ray flares?

THE DEEP CHANDRA IMAGE

RT Instabilities?



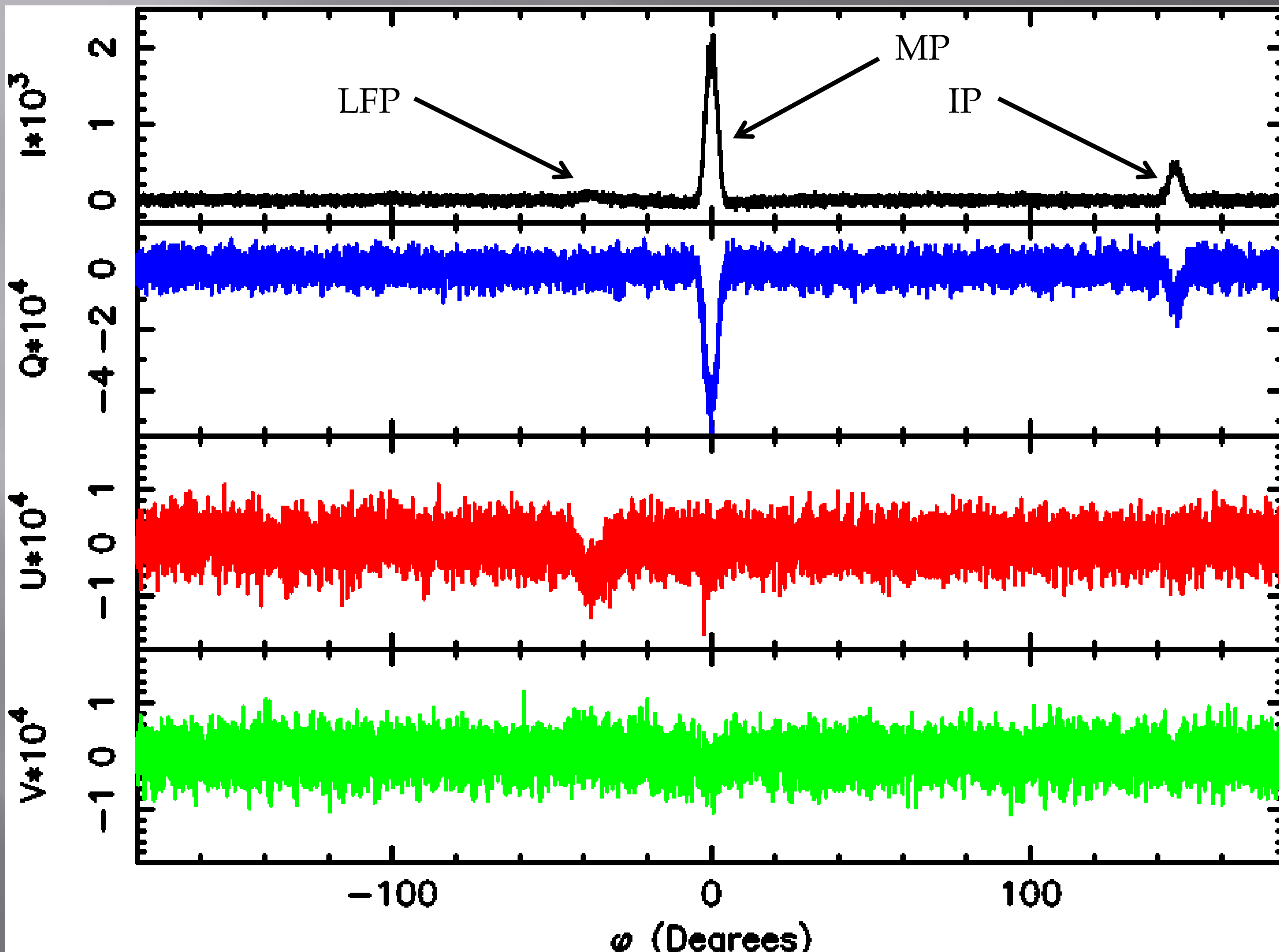
The Stokes Parameters (I,Q,U,V)

$$p_L = (Q^2+U^2)^{1/2} / I$$

$$\psi_L = ½ \tan^{-1}(U/Q)$$

$$p_C = V/I$$

Crab @ 1.4 Ghz

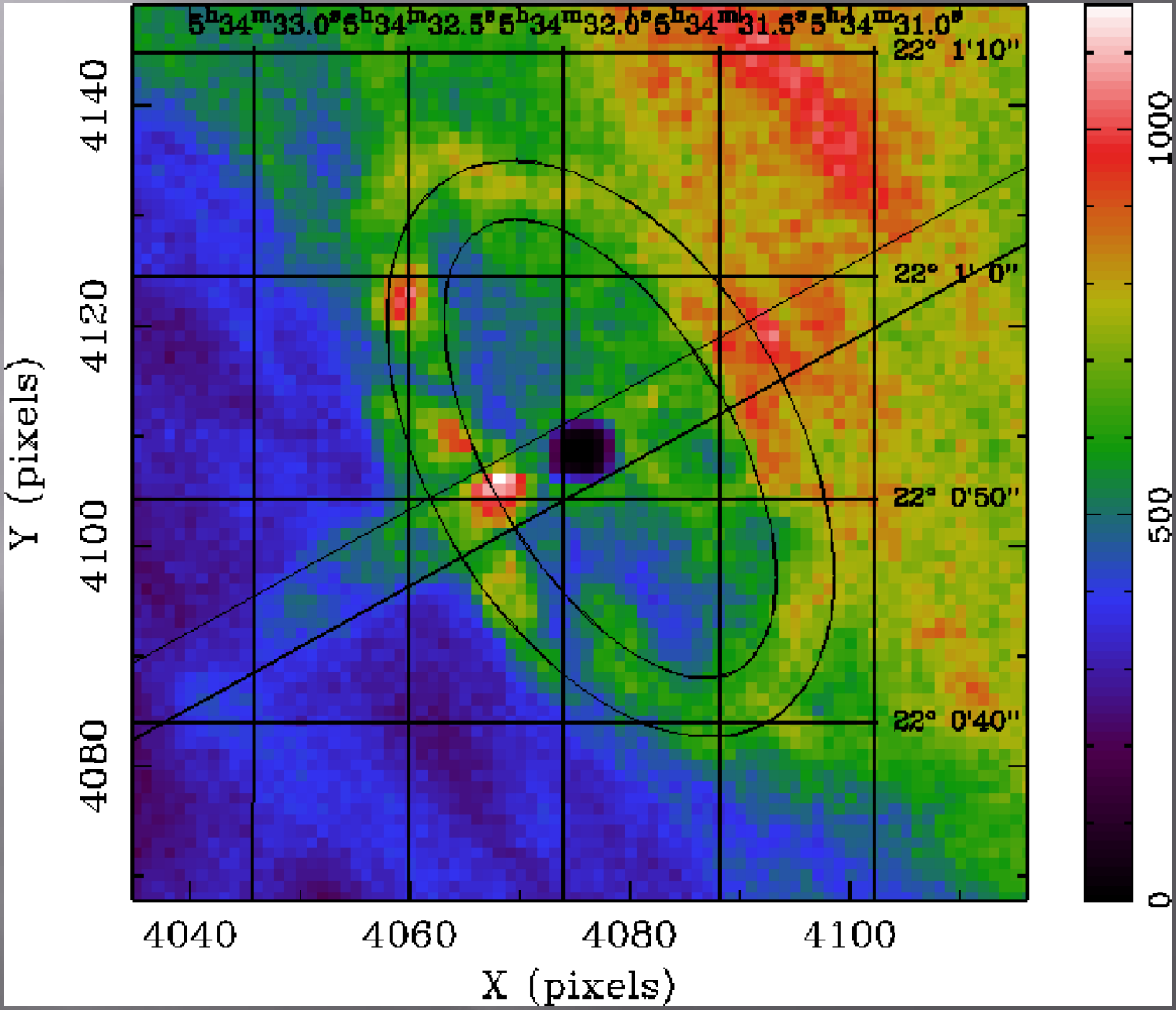


MP
LFP
IP
I*10^3
Q*10^4
U*10^4
V*10^4
2
1
0
0
−2
−4
1
0
−1
1
0
−1
−100
0
100
φ (Degrees)

Observational Conclusions (1.4 GHz)

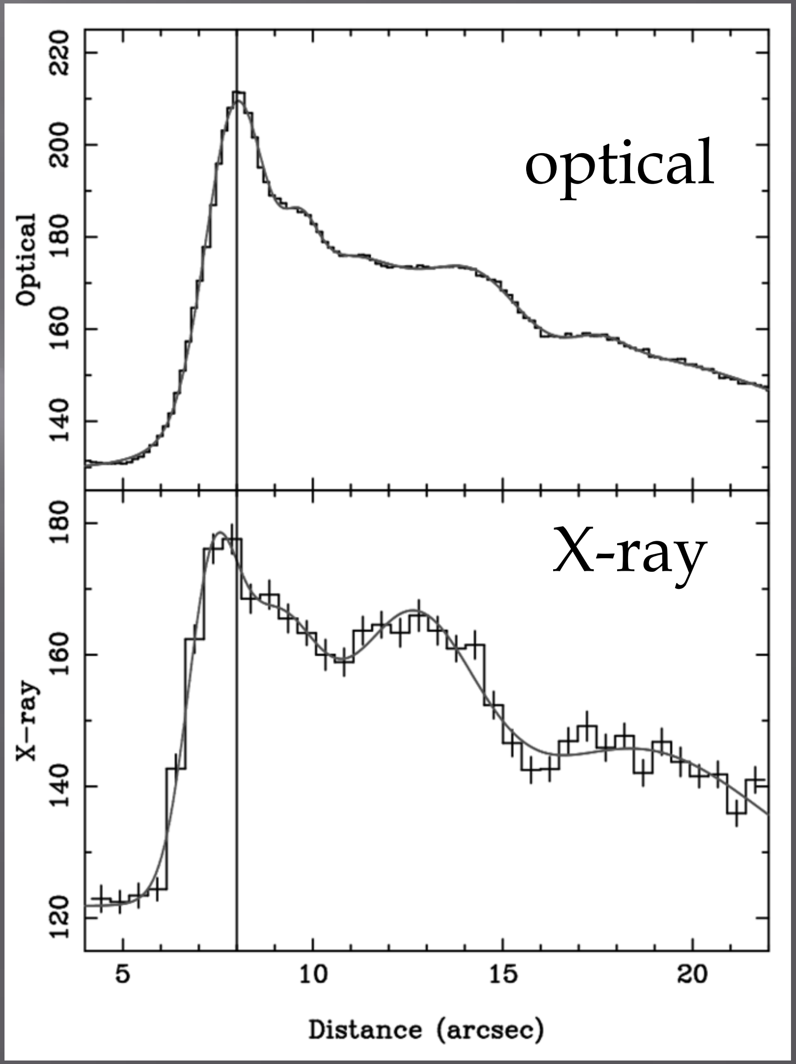
- The main pulse and interpulse polarization properties are very similar
- The LFP polarization properties are very different from those of the main pulse and interpulse
- The behavior is totally dissimilar to the optical in that there is *no* variation of the position angles through the various pulse components

The Northern Wisps

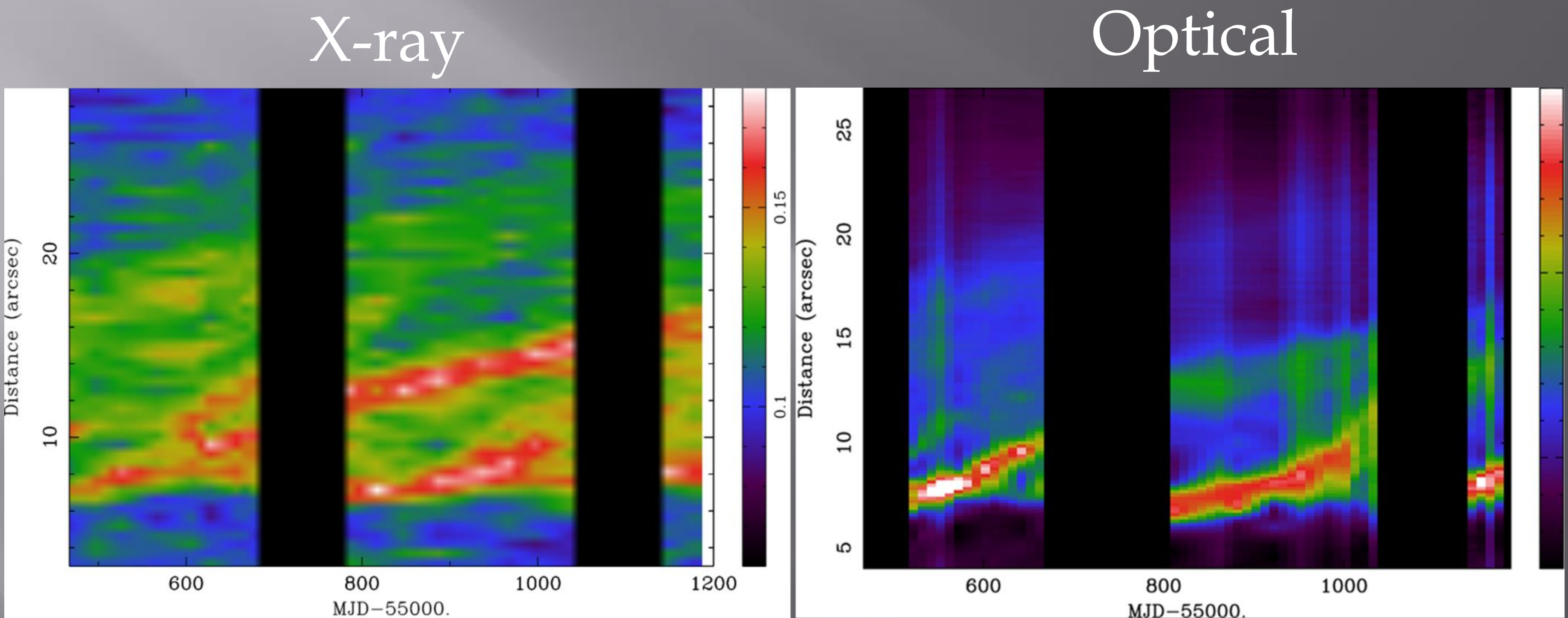


The Northern Wisps (Radial Profiles)

- The X-ray wisp is closer to the pulsar than the optical

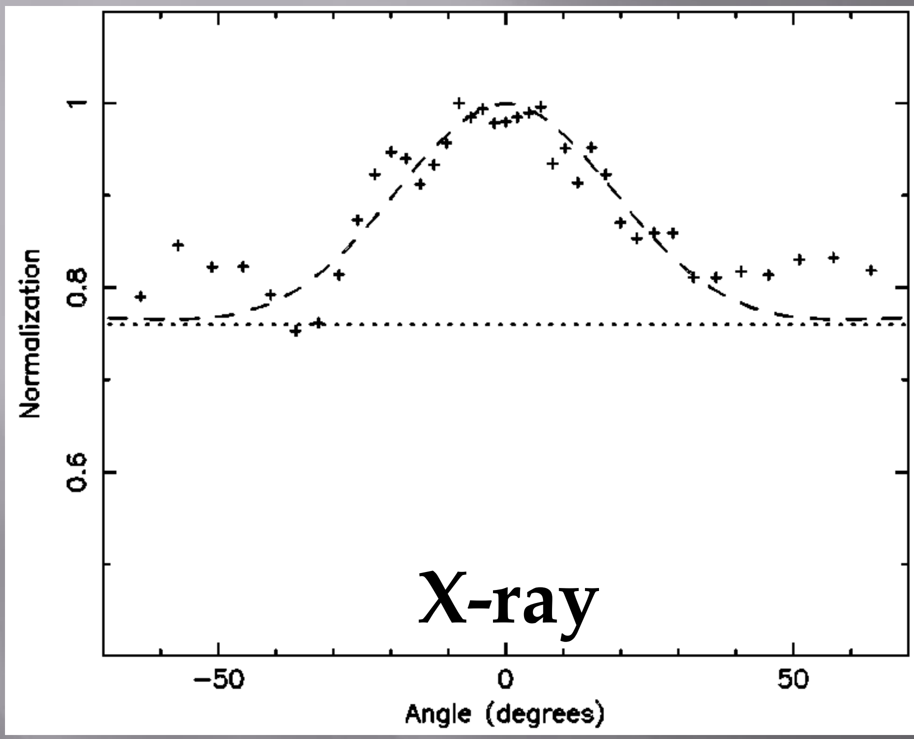


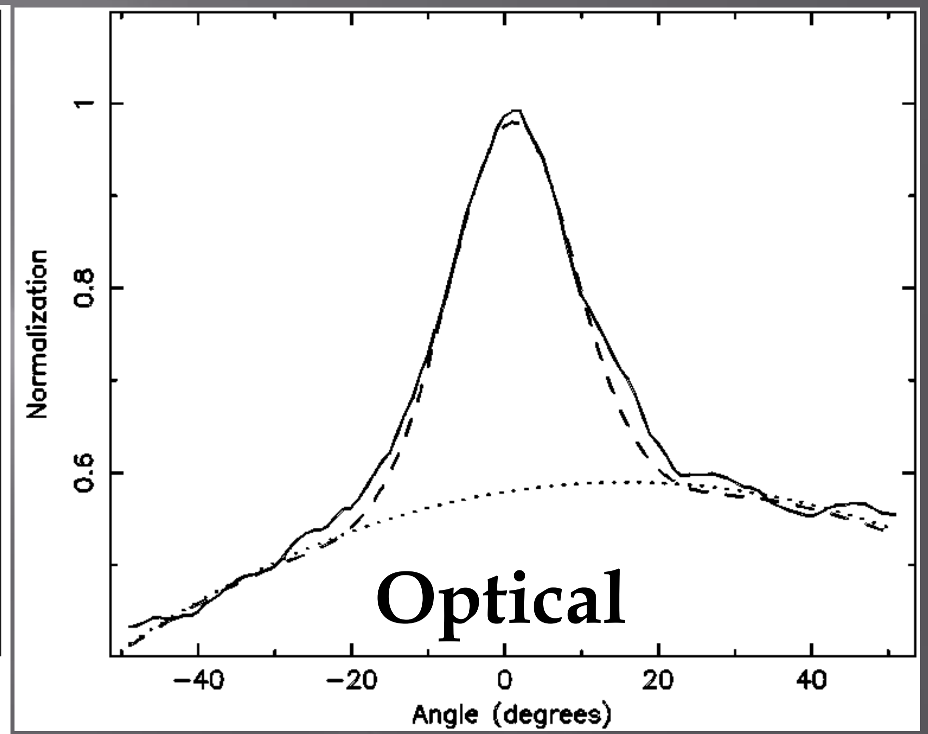
The Northern Wisps (Radial profiles versus time)



- Wisps form when we don't observe ☺
- Apparent velocities range from 0.1 to 0.4 v/c (2kpc)

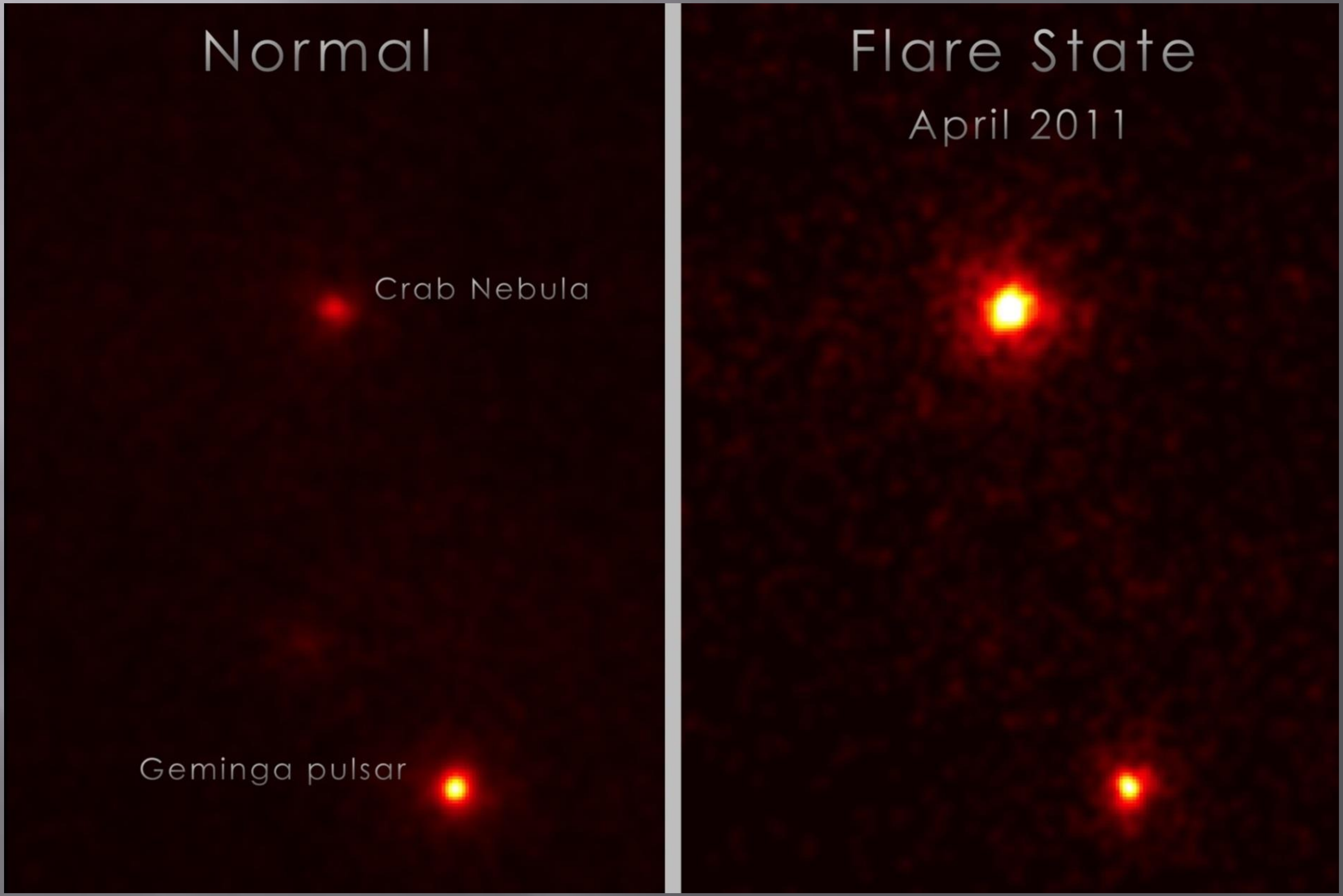
The Northern Wisps
The azimuthal widths



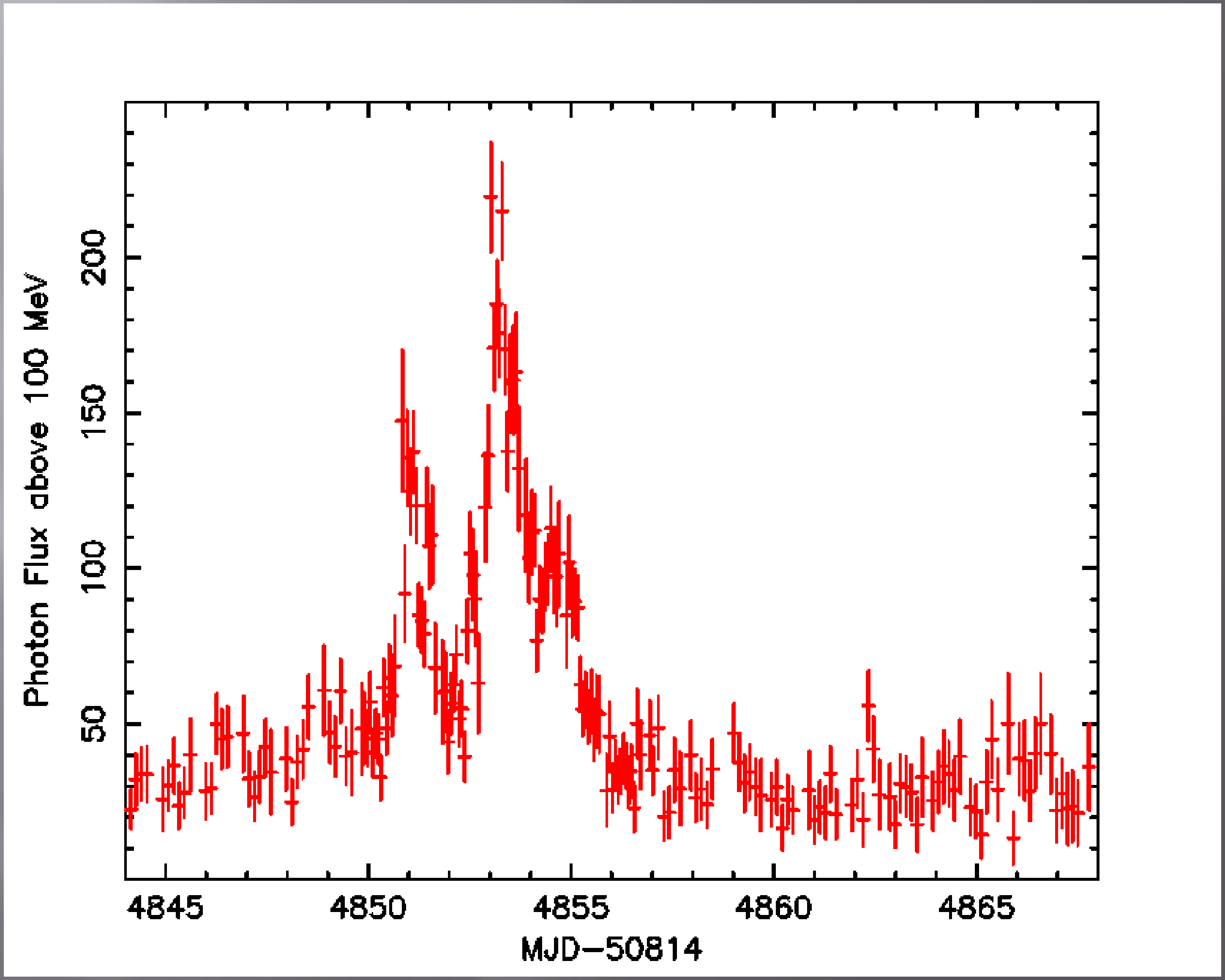


- Different widths imply different Doppler boosting
- Seems to contradict numerical MHD modeling

The April-2011 γ-ray flare



The April-2011 γ-ray flare

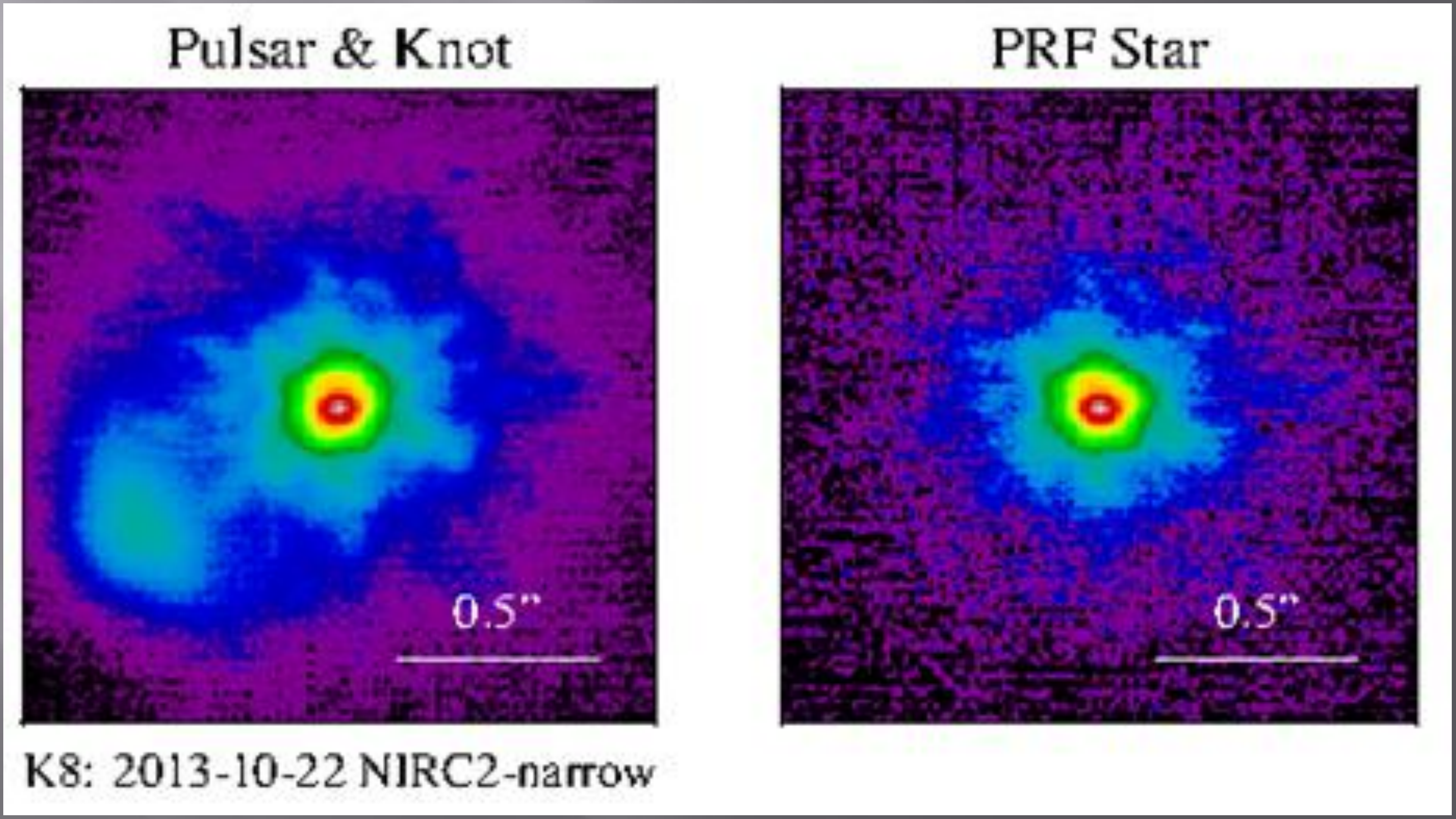


Properties and inferences

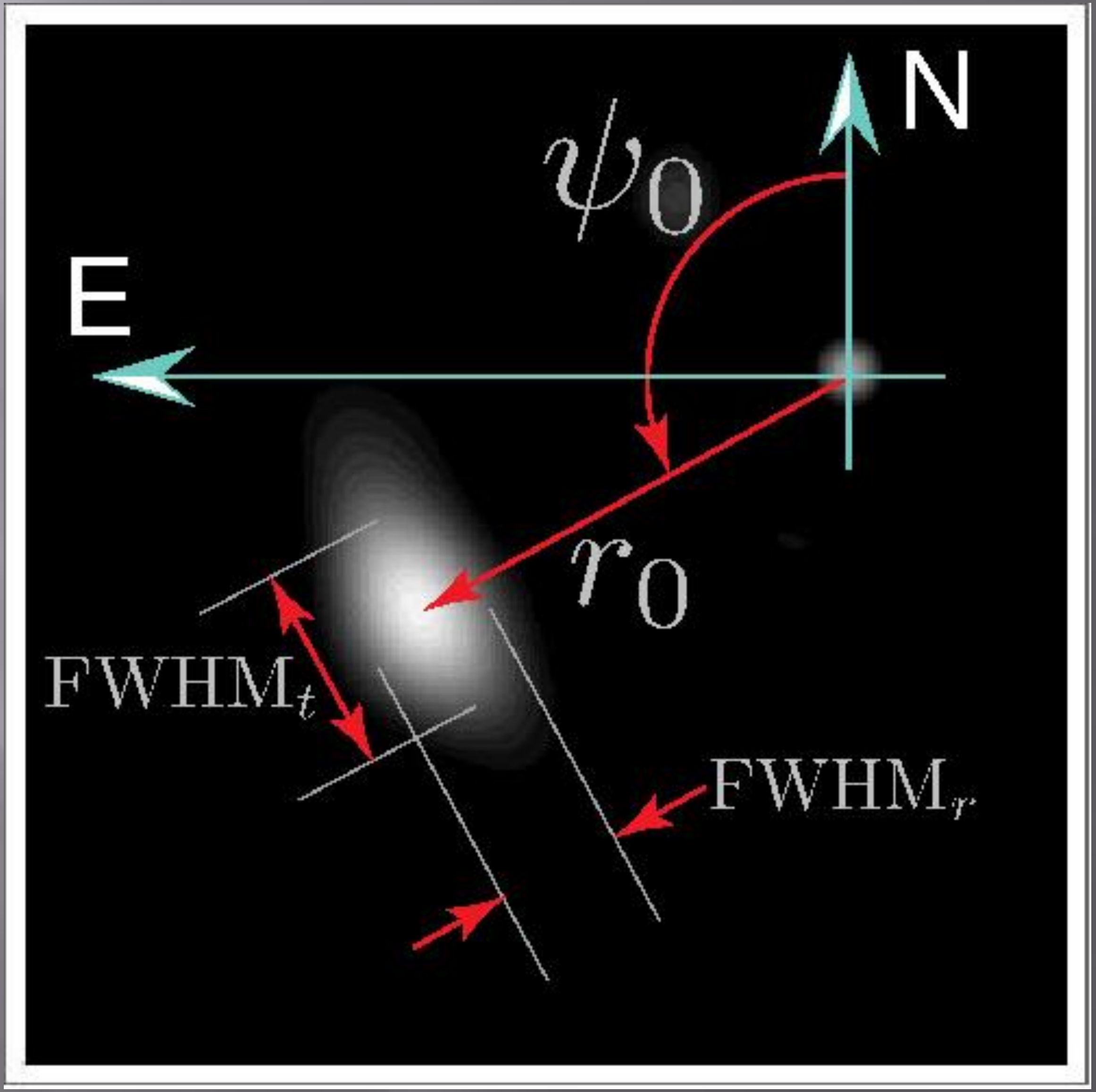
- The size of the emitting region is very small
  - Less than 2×10^{16} cm (0.3" @ 2 kpc)
- A new acceleration mechanism is needed to maintain the PeV radiating particles
  - Plasma instabilities in the Nebula?
  - Magnetic reconnection?
  - Discontinuity in the pulsar wind acceleration?

The inner knot?

- Keck observations with 0.01″ pixels
- Knot-pulsar separation is ~ 0.65″



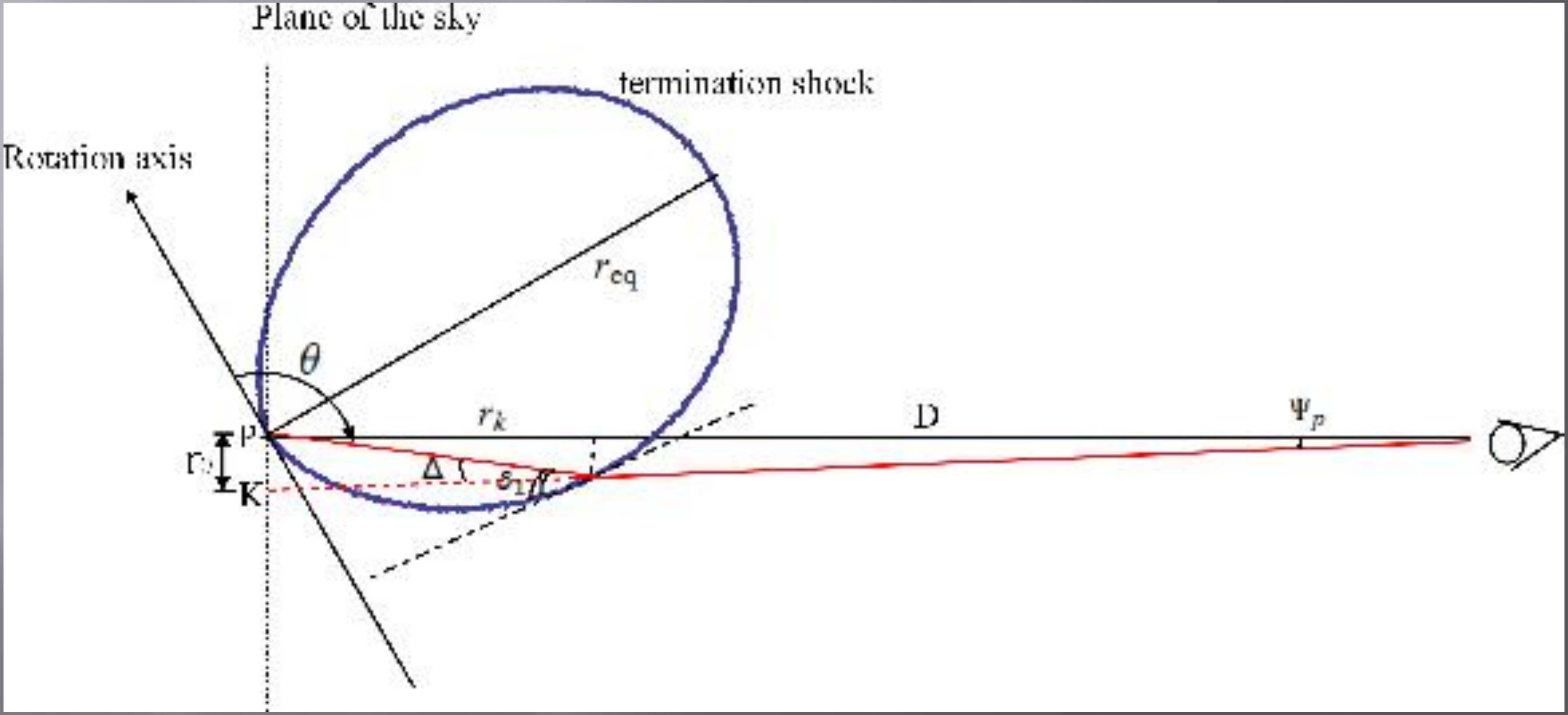
Crab Knot: What we measure



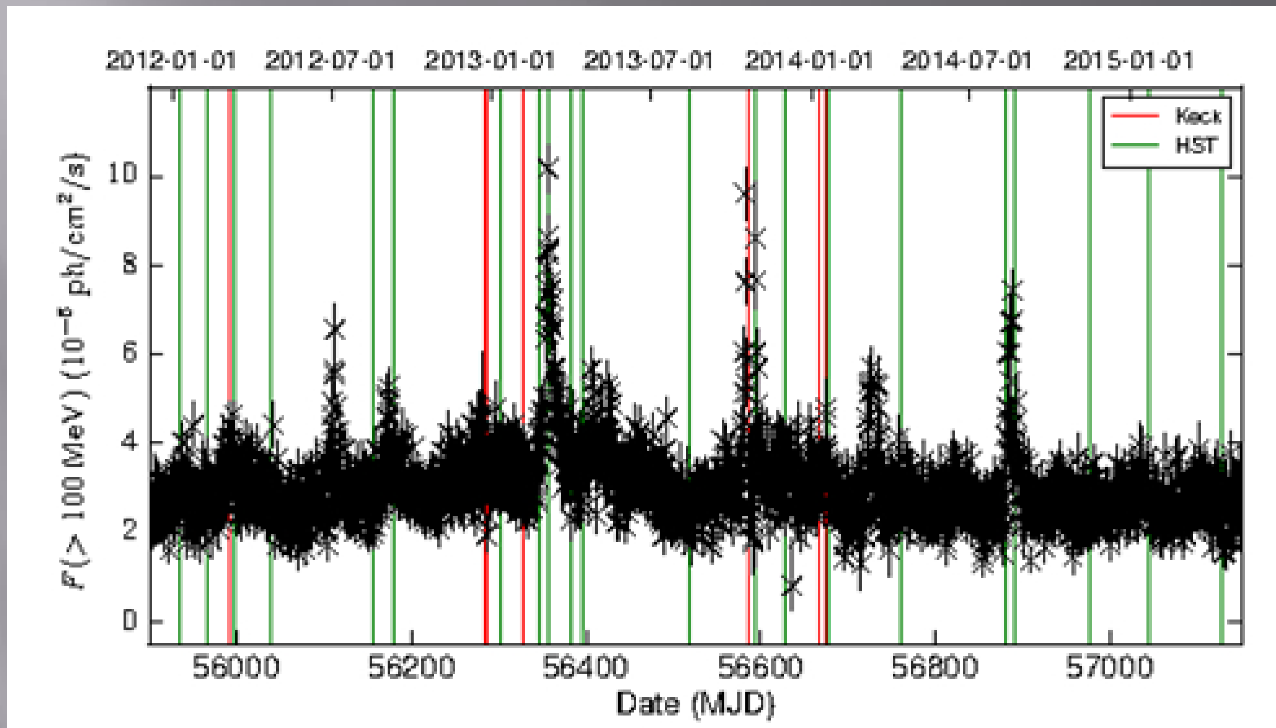
Knot properties

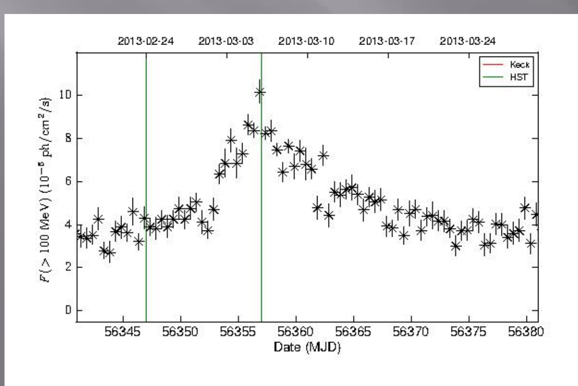
- All infrared-visible light properties correlate with the separation
- Brighter when closer to the pulsar
- Fatter and wider when furthest away

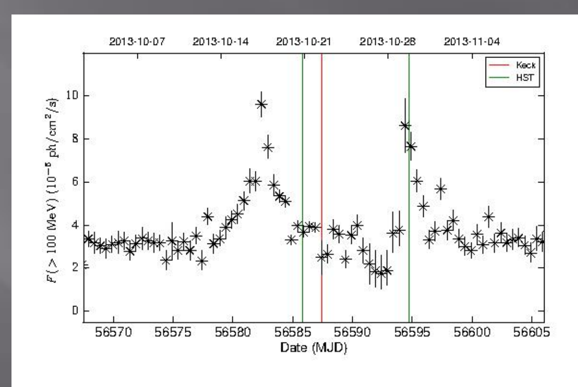
Crab Knot
What we think we are seeing

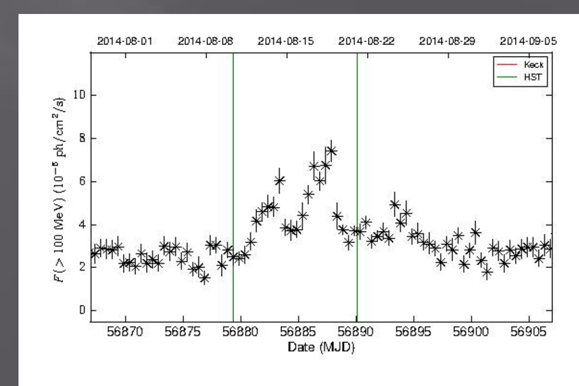


Fermi light curve









Fermi Flux vs Separation